B

Characterization of Non-Symmetric Coplanar Waveguide Discontinuities

Nihad I. Dib and Linda P. B. Katehi

Radiation Lab., University of Michigan, 3228 EECS Building, Ann Arbor, MI 48109-2122

ABSTRACT

A general technique to characterize non-symmetric coplanar waveguide (CPW) discontinuities with air-bridges, where both the fundamental coplanar and slotline modes may be excited together, is presented. First, the CPW discontinuity without air-bridges is analyzed using the Space Domain Integral Equation method. Second, the parameters (phase, amplitude and wavelength) of the coplanar and slotline modes are extracted from an amplitude modulated-like standing wave existing in the CPW feeding lines. Then, a $2n \times 2n$ Generalized Scattering matrix of the discontinuity without air-bridges is derived which includes the occurring mode conversion. Finally, this Generalized Scattering matrix is reduced to an $n \times n$ one by enforcing suitable conditions at the ports which correspond to the excited slotline mode. For the purpose of illustration, the method is applied to a shielded non-symmetric short-end shunt CPW stub whose scattering parameters are also compared with those of a symmetric one.

1 INTRODUCTION

In the state-of-the-art MMIC's, the coplanar waveguide (CPW) represents the transmission line of interest due to several advantages it offers over the conventional microstrip line. However, air-bridges are unavoidable especially when coplanar waveguide circuits are combined with other planar lines and when assymmetries in the structure give rise to the radiating slotline mode [1, 2]. Recently, symmetric coplanar waveguide discontinuities with air-bridges (or bond wires) have been numerically studied and the results of these studies can be found in [3-5]. On the other hand, some results for non-symmetric CPW discontinuities with air-bridges have been presented in the literature [6, 7], but the study performed is far from complete. What makes non-symmetric CPW discontinuities different from symmetric ones is the presence of both the coplanar and slotline modes in the feeding lines which necessitates the use of a special theoretical treatment.

In this paper, a numerical method is presented to characterize non-symmetric CPW discontinuities. This theoretical method is described in section 2 and applied to a shielded non-symmetric short-end shunt stub (Fig.1a) in section 3.

2 THEORY

2.1 Application of the SDIE method

The first step in the analysis is to derive the electric field in the slot apertures of the CPW structure with the air-bridges removed. The theoretical method used to study CPW discontinuities without air-bridges is based on a Space Domain Integral Equation (SDIE) which is solved using the method of moments [8, 9, 10]. In case of transversely symmetric CPW discontinuities (e.g. Fig.1b), the derived field in the feeding lines forms a standing wave of the fundamental coplanar mode away from the discontinuity. Consequently, the hybrid technique developed in [5] can be applied to characterize such discontinuities. However, in case of non-symmetric CPW discontinuities (e.g. Fig.1a), the derived field in the feeding lines looks like an amplitude modulated signal (Fig.2) which is the sum of two fundamental modes (the coplanar and slotline modes). Thus, a special treatment is needed to separate the two modes and derive the scattering parameters of the discontinuity with the air-bridges present as described below.

2.2 Derivation of the mode parameters

As pointed above, the field in the feeding lines derived from the SDIE method (Fig.2) is the sum of the fundamental coplanar and slotline modes each one having its own spatial parameters (wavelength, amplitude and phase). These parameters can be extracted by using either Prony's method [11] or the Standing Wave method. In the first method, the parameters of each mode can be obtained directly by applying Prony's method on the derived amplitude-modulated-like standing wave. In the second method, the standing wave of the fundamental slotline mode in the feeding CPW lines can be obtained by taking the average of the field standing waves in the two slots of each feeding line. On the other hand, the fundamental coplanar mode can be obtained by taking one half the difference of these standing waves. Then, the parameters of each mode can be obtained from the position of the maxima and minima along its corresponding standing wave.

It is found that both methods give the same mode parameters with a difference of less than 0.5%. However, Prony's method has many advantages over the Standing Wave method: (a) it can be used to separate any number of modes in an overmoded structure, especially, if the number of these modes (and preferably their frequencies) are known, (b) relatively short feeding lines, especially for single mode operation, are needed as opposed to the Standing Wave method where the lines have to be close to one guide wavelength.

2.3 The Generalized Scattering matrix

Fig.3 shows the generalized 4-port equivalent representation of a 2-port asymmetric CPW discontinuity without air-bridges. In this representation, two ports are used as input and output for the fundamental coplanar mode and the other two for the slotline mode. In addition, such representation includes the occurring mode conversion at the discontinuity. With the knowledge of the modes parameters, the Network Admittance Matrix can be obtained from which the 4×4 Generalized Scattering Matrix can be derived. In general, $2n$ independent excitations are needed to evaluate the $(2n)^2$ unknown components of the Network Admittance matrix from which the $2n \times 2n$ Generalized Scattering matrix can be derived [12].

2.4 The $n \times n$ scattering matrix

The $2n \times 2n$ Generalized Scattering matrix derived above includes the interactions between the coplanar and slotline modes in the air-bridge-free CPW discontinuity. However, in practice, the slotline mode is always suppressed by connecting the two ground planes of the feeding lines with air-bridges which create a virtual short for this mode. Thus, transverse air-bridges placed at the same reference planes at which the elements of the Generalized Scattering matrix are computed will reduce the 2n-port network representation to an n-port one. This, in effect, will give an $n \times n$ scattering matrix describing the discontinuity under coplanar mode excitation only. Such an effect can be modeled numerically by imposing the following two conditions on the network shown in Fig.3:

$$V_{1s} = 0 \quad (1)$$

$$V_{2s} = 0 \quad (2)$$

It should be noted that such conditions apply to ideal transverse air-bridges as it is the case with typical air-bridges whose parasitic effects have been found to be negligible [1, 2].

3 RESULTS AND DISCUSSION

The technique described above is quite general so that it can be applied to any n-port CPW discontinuity. The method is employed here to analyze the asymmetric short end shunt CPW stub shown in Fig.1a. Since this discontinuity involves a longitudinal air-bridge which connects the two ground planes of the CPW stub, one more step is required after the evaluation of the 2×2 scattering matrix [5]. First, a 2-port lumped element equivalent circuit is derived from this 2×2 scattering matrix. Then, this circuit is modified by incorporating the longitudinal air-bridge from which the new scattering parameters can be obtained (see [5] for details). The scattering parameters of this one-stub discontinuity will be compared to those of the symmetric short-end shunt CPW stub shown in Fig.1b.

In the numerical results shown in Fig.5 and Fig.6, the considered CPW discontinuities are suspended inside a rectangular cavity , as shown in Fig.4, with $h = 400\,\mu m$, $\epsilon_{r1} = 13$, $\epsilon_{r2} = 1$, $S = 75\,\mu m$, $W = 50\,\mu m$, and $h_1 = h_2 = 1.2\,mm$. On the other hand, the CPW stubs are placed at the center of the cavity with a slot width of $25\,\mu m$ and a center conductor of 25 μm.

Fig.5 shows the scattering parameters of the asymmetric stub discontinuity with only the transverse air-bridges taken into consideration. In addition, the scattering parameters of the symmetric stub discontinuity with the air-bridges removed are plotted in the same figure. It can be noticed that both structures exhibit totally different characteristics when the longitudinal air-bridges are removed. It is interesting to observe that the non-symmetric stub without the longitudinal air-bridges still behaves as a shunt stub which is resonating at approximately 27GHz. However, this frequency is not the actual resonant frequency at which the stub is expected to resonate, i.e. at which the stub length is approximately quarter of a wavelength. On the other hand, the behavior of the symmetric stub without the longitudinal air-bridges is far from being a shunt stub [5]. Fig.6 shows the scattering parameters of both discontinuities with all air-bridges taken into consideration. It is seen now that indeed both the non-symmetric and symmetric structures behave as a short-end shunt stub with resonant frequencies of approximately 24.5 GHz and 25.2 GHz respectively. The difference in the resonant frequencies can be attributed to the non-symmetry in one of the discontinuities, and/or numerical errors involved in the computation of the Generalized Scattering matrix.

A comparison between theoretical and experimental results for both the asymmetric and symmetric stub structures without longitudinal air-bridges is shown in Fig.7. For this structure, $h = 400\,\mu m$, $\epsilon_{r1} = 13$, $\epsilon_{r2} = 2.2$, $S = 125\,\mu m$, $W = 85\,\mu m$, and $h_1 = h_2 = 3.175\,mm$, and the CPW stubs have a slot width of $50\,\mu m$ and a center conductor of 75 μm. It can be seen that the agreement between theory and experiment is very good which verifies the validity of the presented theoretical technique. The anomalous behavior in the theoretical data noticed after 30 GHz is due to resonances in the partially filled lower cavity.

The developed numerical technique will be extended to analyze other asymmetric CPW discontinuities in shielded as well as open environment [10]. Such an analysis will also study of the effect of air-bridges on radiation loss and results will be presented in the symposium.

4 CONCLUSIONS

A general technique to characterize non-symmetric CPW discontinuities, where both the fundamental coplanar and slotline modes may be excited, has been developed. At first, the planar structure with the air-bridges removed is analyzed using the SDIE method which results in an amplitude modulated-like standing wave pattern in the feeding

CPW lines. Second, the two modes forming such a standing wave are separated by either using Prony's method or the Standing Wave method. Third, a $2n \times 2n$ Generalized Scattering matrix is obtained which includes the occurring mode conversion due to the discontinuity. Finally, this matrix is reduced to an $n \times n$ scattering matrix by forcing the slotline mode voltages at the corresponding ports to be zero. This approach has been applied to the non-symmetric short-end shunt CPW stub and has shown very good numerical stability. The scattering parameters of this discontinuity have been compared to those of a symmetric short-end shunt CPW stub, and have been found to be similar when all bridges are taken into consideration. A set of theoretical data was compared to experimental results, and the agreement between both was very good.

5 ACKNOWLEDGMENT

The authors wish to thank Mr. George Ponchak for supplying the experimental data, and thank Prof. Emad Ebbini for the useful discussions on the use of Prony's method. This work was supported by the National Science Foundation under contract ECS-8657951.

REFERENCES

[1] N. Koster, *et al*, " Investigation of Air Bridges Used for MMICs in CPW Technique, " *Proc. of 19th European Microwave Conference* , pp. 666-671, Sep. 1989.

[2] T. Hirota, Y. Tarusawa, and H. Ogawa, " Uniplanar MMIC Hybrids - A Propose of a New MMIC Structure ", *IEEE Trans. on MTT*, pp. 576-581, June 1987.

[3] M. Rittweger, M. Abdo and I. Wolff, "Full-Wave Analysis of Coplanar Discontinuities Considering Three-Dimensional Bond Wires, " *in 1991 IEEE MTT-S Digest*, Boston, pp. 465-468.

[4] K. Beilenhoff, W. Heinrich and H. Hartnagel, " The Scattering behavior of Air Bridges in Coplanar MMIC's, " *Proc. of 21st European Microwave Conference* , pp. 1131-1135, Sep. 1991.

[5] N. Dib, P. Katehi and G. Ponchak, "Analysis of Shielded CPW Discontinuities with Air Bridges, " *in 1991 IEEE MTT-S Digest*, Boston, pp. 469-472.

[6] M. Rittweger, *et al*, "Full-Wave Analysis of a Modified Coplanar Air Bridge T-Junction, " *Proc. of 21st European Microwave Conference* , pp. 993-998, Sep. 1991.

[7] R. Bromme and R. Jansen, "Systematic Investigation of Coplanar Waveguide MIC/MMIC Structures Using a Unified Strip/Slot 3D Electromagnetic Simulator, " *in 1991 IEEE MTT-S Digest*, Boston, pp. 1081-1084.

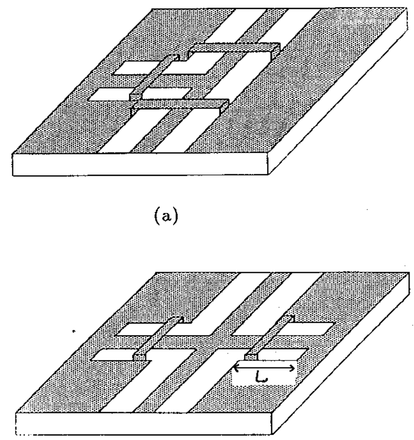
[8] N. Dib and P. Katehi, "Modeling of Shielded CPW Discontinuities Using the Space Domain Integral Equation Method (SDIE), " *Journal of Electromagnetic Waves and Applications*, No. 4/5, 1991, pp. 503-523.

[9] N. Dib, P. Katehi, G. E. Ponchak, and R. N. Simons, "Theoretical and Experimental Characterization of CPW Discontinuities for Filter Applications, " *IEEE Trans. on MTT*, pp. 873-882, May 1991.

[10] W. Harokopus Jr. and P. Katehi, " Radiation Loss from Open Coplanar Waveguide Discontinuities," *in 1991 IEEE MTT-S Digest*, Boston, pp. 743-746.

[11] S. Marple Jr., *Digital Spectral Analysis with Applications*, Prentice-Hall, 1987.

[12] D. Sazonov, A. Gridin and B. Mishustin, *Microwave Circuits*, Mir Publishers, Moscow, 1982.



(a)

(b)

Figure 1: (a) The non-symmetric short-end shunt CPW stub. (b) The symmetric short-end shunt CPW stub.

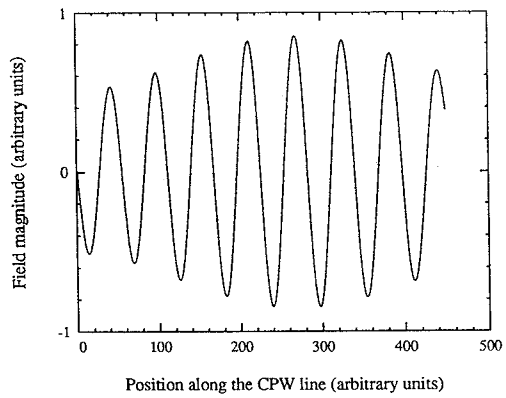


Figure 2: A sample amplitude modulated-like standing wave existing in the feeding CPW which results from the superposition of the fundamental coplanar and slotline modes.

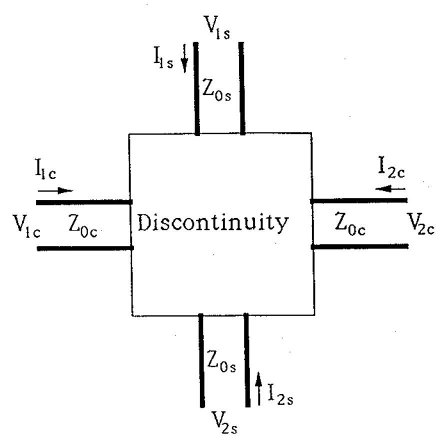


Figure 3: A generalized 4-port equivalent representation of a 2-port CPW non-symmetric discontinuity (without air-bridges) where the fundamental coplanar and slotline modes are excited.

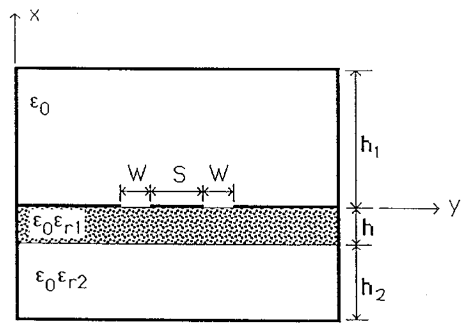


Figure 4: A cross section of a coplanar waveguide inside a cavity.

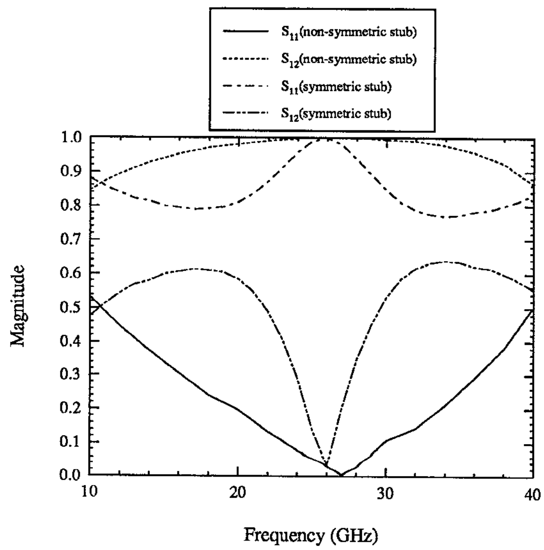


Figure 5: Scattering parameters of both the symmetric and non-symmetric short-end shunt CPW stub discontinuities (Fig.1) without the longitudinal air-bridges. ($L = 1100\,\mu m$)

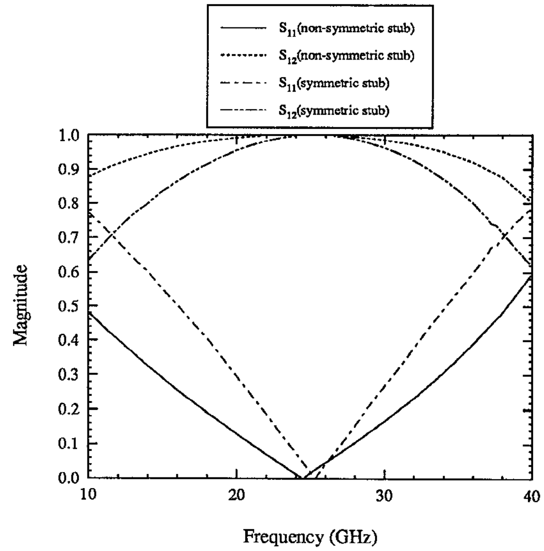


Figure 6: Scattering parameters of both the symmetric and non-symmetric short-end shunt CPW stub discontinuities with all air-bridges taken into consideration. ($L = 1100\,\mu m$)

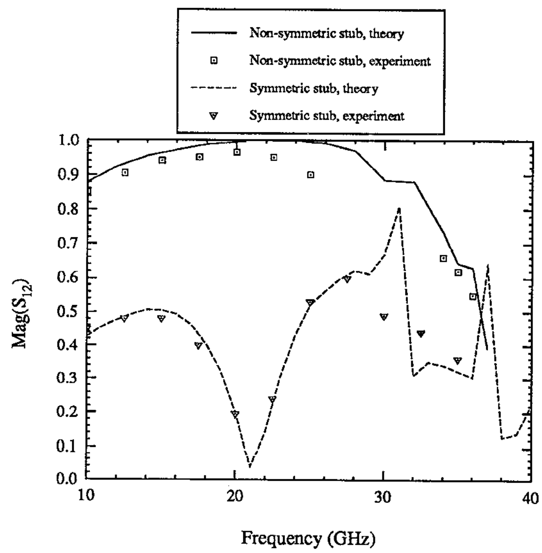


Figure 7: Scattering parameters of both the symmetric and non-symmetric short-end shunt CPW stub discontinuities without the longitudinal air-bridges. ($L = 1360\,\mu m$)